Sustainable Electrical Power Systems

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Credit: Wikimedia commons, David Tribble, no changes

Today's Electric Power Grid

- Today's electric power systems have grown up incrementally and haphazardly – they were not designed from scratch
- They form ***complex systems*** that are in constant change:
  - Loads change
  - Breakers go out
  - There are unexpected disturbances
  - They are at the mercy of uncontrollable influences such as weather
- Cascading failures can have dramatic consequences (e.g., widespread blackouts)

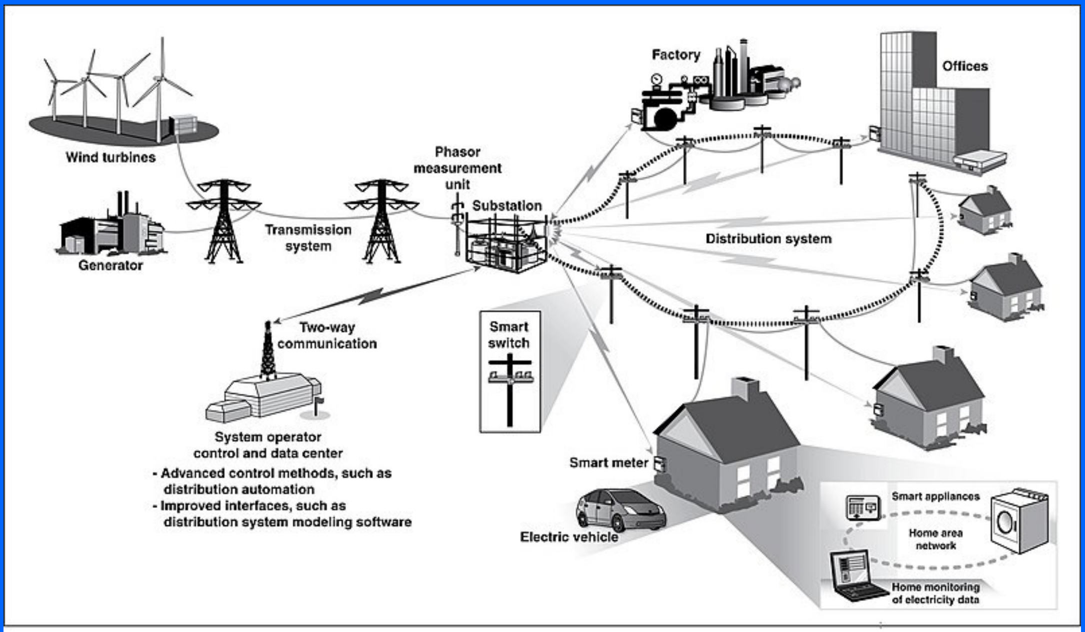
Credit: Wikimedia commons,
Camerafiend at English Wikipedia., **no changes**

Sustainability of Today's Electric Power Grid

- Today's grid is managed through large parallel computers/supercomputers with the system not set up for this type of management.
- But such machines can help when there are disruptions/disturbances.
- ***Sustainability:*** We might not be able to return the system to its exact prior configuration, but if we don't come close, we create vulnerabilities from unkown configurations. (A great 2003 North American blackout resulted from making what seemed an innocent change.)

Sustainability of Today's Electric Power Grid

- This is in contrast to sustainability of areas where there are massive floods or fires, where we might aim to rebuild to a quite different configuration.
- ***Challenge: How can humans and computers interact to return the power grid to a relatively normal configuration?***



Source: GAO analysis.

Credit: Wikimedia commons, US General Accountability Office

The Need for a Sustainable Grid

- The electric power grid is a massive, complex system.
- With sufficient information to determine what is happening in real time, grid operators would be able to contain a cascading outage or perhaps prevent one altogether.
- However:
  - The grid has hundreds of thousands of miles of transmission lines
  - Decisions have to be made really fast – in real time or faster

Acknowledgement: Article by Sara Robinson, SIAM News, Oct. 2003

The Need for a Sustainable Grid

- Power grid operators need to see several moves ahead, sorting through millions of possible scenarios, to choose an appropriate response.
- It could be that humans just can't respond quickly enough or calculate fast enough.
- Either we give them some tools to aid them or we put the decision making into the hands of machines.
- Machines are very good at these large, complex searches.
- What is called for is a new complex, adaptive system that has ***self-healing properties***.
- But humans are needed to train machines to be self-healing.

Acknowledgement: Article by Sara Robinson, SIAM News, Oct. 2003

The Need for a Sustainable Grid

- This idea of a "***self healing grid***" was initiated in 1998 in a joint initiative in the US of the Electric Power Research Institute (EPRI) and the Dept. of Defense called the "Complex/Interactive Networks/Systems Initiative.
- In 2001 EPRI introduced the term "Intelligrid"
- Since then, EPRI and the US Dept. of Energy have adopted the term "smart grid."

Autonomic Computing

- "Self-healing, complex adaptive system" is a concept that was generalized in the early 2000's through the notion of "***autonomic computing***," popularized by IBM.
- The goal of autonomic computing is to create computer systems that manage themselves with "high level" guidance from humans.
- ***But humans have to give them the ability to manage themselves.***

Autonomic Computing

- Motivation: Large-scale systems have become too difficult for humans to configure, maintain and tune and too difficult for us to predict their behavior.
- The challenge is to make them ***self-sustaining, self-healing, self-protecting***: How do we design complex systems to automatically discover and correct faults?
- This challenge is key to making a "*sustainable* ***grid***."

Sustainable Grid

- ***"Sustainable grid" applications are grounded in massive amounts of data that will enable better decisions.***
- **Phasor measurements** of current and voltage by amplitude and phase can provide "MRI quality" visibility of the power system.
- **Traditional SCADA (Supervisory Control & Data Acquisition) measurement** provides
  - Bus voltages
  - Line, generator, and transformer flows
  - Breaker Status
  - *Measurement every 2 to 4 seconds*

Grid monitoring using synchophasors. Credit: Siemens

Sustainable Grid

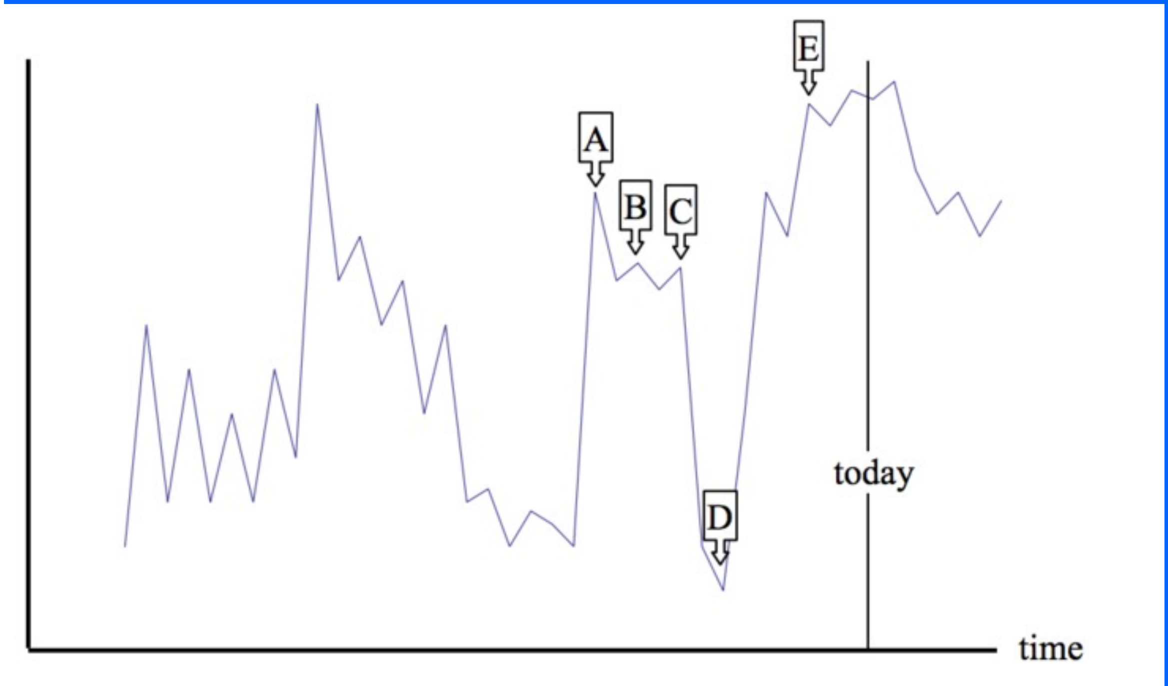
- **Phasor technology and phasor measurements provide additional data:**
  - Voltage and current phase angles
  - Frequency rate of change
  - ***Measurements taken many times a second***
  - ***Human operators may not be able to sense an anomaly that fast or take corrective action that fast.***

Credit: Wikimedia commons, Angelo DeSantis

Sustainable Grid: Challenges

Anomaly Detection:

- New algorithmic methods are needed to understand, process, visualize data and find anomalies rapidly.



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Susstainable Grid: Challenges

Grid Robustness:

- How can we design "control" procedures so that the grid can quickly and efficiently respond to disturbances and quickly be restored to its healthy state?
- Need fast, reliable algorithms to respond to detected problems.
  - Should not necessarily require human input
  - Has to be able to handle multiple possible "solutions"
  - Has to be able to understand what to do if all possible solutions are "bad"

Sustainable Grid: Challenges

Developing Self-healing Systems:

- Need
  - Efficient monitoring and probing (without overwhelming system resources)
  - Statistical prediction of impending problems
  - Automated problem location and probe selection
  - Automated planning and learning of corrective action workflows
- But what is the role of the human operator? In what cases should they have control/approval over machine-generated responses?
- In what situations can a machine bypass the set of allowable responses a human operator has given them?